Carabid beetles in commercial raspberry fields in the Fraser Valley of British Columbia and a sampling protocol for *Pterostichus melanarius* (Coleoptera: Carabidae)

DAVID A. RAWORTH, SHARON J. CLEMENTS and CONNIE CIRKONY
PACIFIC AGRI-FOOD RESEARCH CENTRE, P.O. BOX 1000 - 6947 #7 HIGHWAY AGASSIZ, BC V0M 1A0

YVES BOUSQUET
EASTERN CEREAL AND OILSEED RESEARCH CENTRE, AGRICULTURE AND AGRI-FOOD CANADA K.W. NEATBY BLDG., OTTAWA, ON K1A 0C6

ABSTRACT

Carabid beetles were sampled in 15 raspberry fields in the Fraser Valley of BC from April to September, 1994. At least 28 species were caught, but one, *Pterostichus melanarius* (Illiger), dominated with 80% of all individuals. Eight of the nine most numerous species (>200 individuals caught) were introduced in North America. Significant, 30-fold differences were detected between fields with respect to abundance of seven of these species. The differences could not be attributed to soil type, type of habitat at the edge of the field nearest the traps, or spray history. A sampling protocol for pest managers was developed in which 1 to 3 consecutive weekly samples during July provide a relative index of annual abundance of *P. melanarius* throughout the season. Traps should be set at a standard distance from the edge of a field because numbers increase with distance from the edge. At least 10 traps per field are required for reasonable precision.

Key words: Carabidae, raspberry, sampling, *Pterostichus melanarius*, predator

INTRODUCTION

Raspberry is an important crop in the Pacific Northwest. It is attacked by a number of key pests, including *Otiorhynchus sulcatus* (F.) (Coleoptera: Curculionidae), *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae) and other weevils and lepidoptera. These pests are in turn attacked by carabid beetles at some point in their life cycles. Thiele (1977) suggests that the assemblage of carabids that occur in any given area depends largely on the plant community. Raspberry pest management could therefore benefit from cultural practices that alter the habitat of carabids in ways that increase their predatory capacity. Raspberry fields provide a unique opportunity for cultural manipulations because there is considerable land to work with (rows are spaced 3 m apart), the soil between the rows may or may not be cultivated, annual or perennial cover crops may or may not be planted between the rows, and a planting may last for 35 years or more. Furthermore, the crop is grown over a large geographical area from Oregon, north to British Columbia, with a wide range of conditions over which to test cultural manipulations. This approach has been studied in other agricultural systems. Diversified agroecosystems appear to have positive effects on predacious and parasitic insects, including carabid beetles (Nentwig 1988; Thomas *et al.* 1991; Lys *et al.* 1994). Direct demonstration that this effect decreases pest populations is so far lacking, but work using other techniques has shown the importance of carabid beetles in regulating pests such as aphids (e.g. Edwards *et al.* 1979) and root maggots (e.g. Grafius and Warner 1989).

Our first concern was to determine the nature of the existing carabid assemblage. Levesque and Levesque (1994) report on carabids found in a single raspberry plantation and adjacent sites in southern Quebec. Here, we report on carabids found in 15 commercial raspberry fields that extend from Westham Island to Sumas Prairie (about 75 km) in the Fraser Valley of BC: the species observed; their relative numbers; differences in numbers of the dominant species between fields, soil types, adjacent habitats and spray histories; and the effect of trap location and time of season on the number of carabids caught. These data are essential to plan future cultural manipulations and develop sampling protocols for pest managers.

Table 1.

Some characteristics of 15 commercial raspberry fields in the Fraser Valley, BC sampled for carabid beetles in 1994.

Field	Location	Margin[1] vegetation	Soil symbol[2]	Soil group[3]	Pesticide[4]
1	Sumas	forest	BT	1	2
2	Abbotsford	forest	MH-AD	2	4
3	Abbotsford	forest	MH	2	4
4	Clearbrook	forest	MH	2	2
5	Clearbrook	grass	MH	2	3
6	Clearbrook	raspberry	MH-AD	2	-
7	Clearbrook	forest	MH	2	2
8	Clearbrook	grass	AD	3	3
9	Clearbrook	raspberry	AD	3	2
10	Clearbrook	raspberry	AD	3	3
11	Clearbrook	raspberry	AD	3	-
12	Langley	forest	W-AB	4	4
13	Langley	forest	W-SC	4	4
14	Westham Island	grass	WS	5	-
15	Westham Island	raspberry	WS-CT	5	1

[1] Margin nearest traps. Adjacent grass was usually ploughed during the season.

[2] BT, Bates, medium-textured, imperfect drainage; MH, Marble Hill, medium-textured, well drained; AD, Abbotsford, medium-textured, well to rapid drainage; W, Watcom, moderately fine textured, moderately well drained; AB, Albion, moderately fine to fine textured, moderately poor to poor drainage; SC, Scat, moderately fine textured, poor drainage; WS, Westham, moderately fine to medium-textured, poor to moderately poor drainage; CT, Crescent, medium to moderately fine textured, moderately poor to poor drainage, (Luttmerding 1980, 1981).

[3] Soil grouping for analyses.

[4] 1, no insecticides; 2, Diazinon; 3, Diazinon and Malathion; 4, Diazinon and Guthion or Furadan; -, unknown.

MATERIALS AND METHODS

Commercial raspberry fields were chosen from a wide range of ecological and cultural situations in the Fraser Valley (Table 1). These fields were sampled continuously from 26 April to 28 September 1994 using pitfall traps. The beetles were collected and the traps cleared weekly until 30 August, and then bi-weekly until 28 September. Pitfall traps were made from tapered plastic beer cups (9.5cm diam top). A hole (1.6 cm diam) was cut in the bottom centre of pairs of cups. One cup was sunk in the soil with the rim just below the soil surface, to form a mould. Lumite Saran screening (13 x 13 threads/cm) was glued over the hole in the other cup using contact cement. The screen kept smaller carabids like *Bembidion* spp. from escaping, but allowed water through. The screened cup was placed inside the first, mould cup, so that the soil was level with the rim. This second cup was easily removed to empty the trap. The traps were placed between raspberry plants within a row, where they did not interfere with daily farm operations. Five traps were located 6 m apart, within 2 m of an edge of a field, and five more were located 6 m apart, within 50 m of the same edge. A plywood cover (10.5 x 10.5 x 1.7 cm), supported by wire (9 cm x 1.5 mm diam) driven into the wood at the four corners, was set in place 4 cm above each cup to reduce contamination from leaf litter.

A reference collection of carabids was developed with material identified at the Biosystematics Research Centre (BRC), Agriculture Canada [now the Eastern Cereal and Oilseed Research Centre (ECORC), Agriculture and Agri-Food Canada] in Ottawa. Identification was based on Hatch (1953). Most beetles were identified in the field, but specimens that were in doubt were brought back to the laboratory for closer examination, and sent to BRC for identification when necessary. Beetles caught in the pitfall traps were released several kilometres from the study field to eliminate the possibility of recapture.

Regression, ANOVA and chi-square (SAS Institute Inc. 1990) were used to analyze the data. Catches from each trap were summed over time for all analyses except those relating to temporal activity. Regression of ln(variance) on ln(mean), of data from the five traps at each location in a field was used to determine the appropriate transform according to Southwood (1966); data are reported on both transformed and back-transformed scales (Fig. 1). Differences in beetle numbers between fields were tested using the trap-location-within-field residual mean square; and differences between environmental categories (soil type, adjacent habitat and spray history) were tested using their respective field-within-category residual mean square.

RESULTS AND DISCUSSION

At least 28 carabid species were caught in the commercial raspberry fields (Table 2). These species have a wide range of prey: *Bembidion* species - insect eggs (van Dinther and Mensink 1971); *Calathus fuscipes* (Goeze) and *Pterostichus melanarius* (Illiger) - caterpillars, aphids and weevils (Skuhravý 1959); *Carabus* species - arthropods and earthworms (Thiele 1977). *Carabus granulatus* L. also eats slugs (Scherney 1955). Eight of the nine most abundant species (>200 individuals caught) were introduced in North America. The dominant species was *P. melanarius* with 30984 individuals caught in 3404 trap-weeks (number of traps x weeks). The next most abundant species was *C. fuscipes*, with 1,975 individuals. This is a typical dominance structure associated with reduced habitat variation on agricultural land - "few species definitely playing a leading role" (Thiele 1977). Levesque and Levesque (1994) observed a similar dominance structure in a raspberry field in Québec. The assemblage of beetles was different, but as in our study, most were *P. melanarius*. Fourteen species and *Amara* spp. were active during the entire sampling period. However, each species had a period of peak activity, either during April-May or August-September (Table 2).

Data for the nine species (and *Amara* spp.) with more than 200 individuals caught during the sampling period were analyzed statistically. There were significant differences between fields with respect to the number of individuals of *Amara* spp., *Anisodactylus binotatus* (F.), *Bembidion dyschirinum* LeConte, *Calathus fuscipes*, *Carabus nemoralis* O.F. Müller, *C. granulatus*, *Pterostichus melanarius* (F = 6.0-37.4; df = 14,15; $p < 0.01$; e.g. Fig. 1), and *Clivinia fossor* (L.) ($F = 3.2$; df = 14,15; $p < 0.05$), but not with respect to *Harpalus affinis* (Schrank) and *Trechus obtusus* Erichson (F = 1.3-1.6; df = 14,15; $p > 0.05$). So differences between fields were detected for most of the species tested, and the differences were large - in the order of 30-fold or more (back-transformed scale, Fig. 1). Furthermore, the pattern of species dominance was not the same from field to field ($\chi^2 = 55688$; 126 df; e.g. Fig. 1).

The differences between fields could not in general be attributed to soil type, adjacent habitat or spray history (21 out of 24 tests; $p > 0.05$). This is surprising - Thiele (1977) suggests that soil, heavy (clay) *vs.* light (sandy), has an overriding quantitative and qualitative effect on carabid

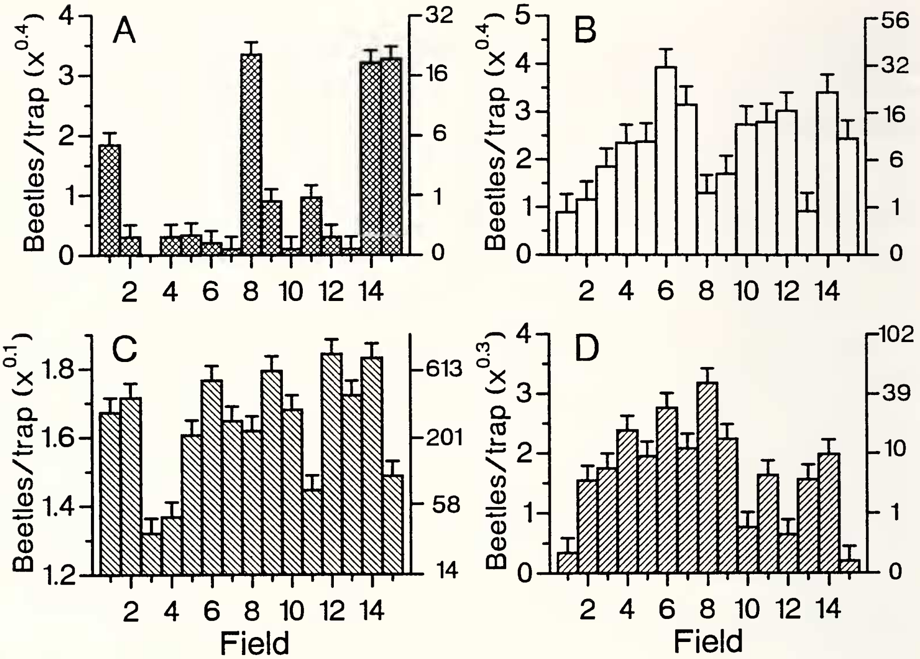

Figure 1. Mean number of carabid beetles per pitfall trap in 15 commercial raspberry fields in the Fraser Valley, BC, from April to September 1994: **A**, *Carabus granulatus*; **B**, *Bembidion dyschirinum*; **C**, *Pterostichus melanarius*; **D**, *Calathus fuscipes*. Fields numbered as in Table 1; vertical axes on right in back-transformed scale; vertical bars are +1SE on transformed scale.

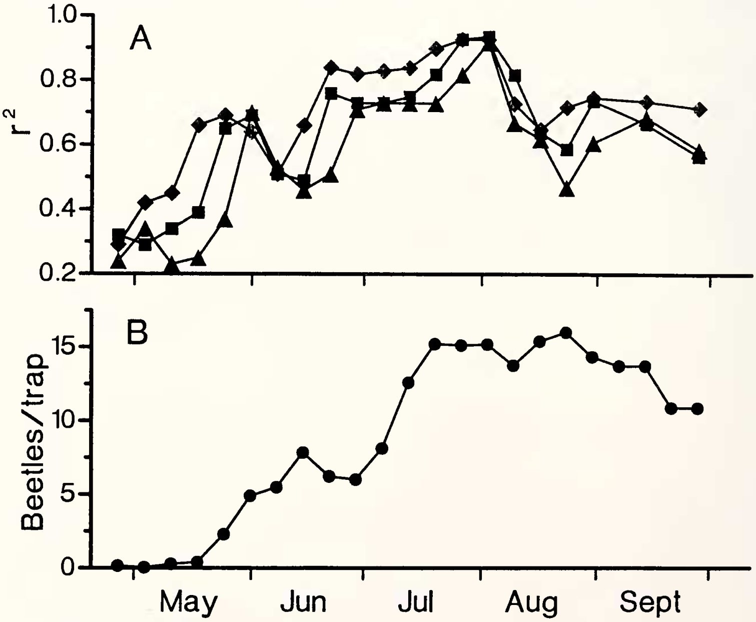

Figure. 2. Correlation coefficients between the number of *Pterostichus melanarius* caught per pitfall trap [summed over 1- (triangle), 2- (square), and 3- (diamond) consecutive weekly samples] and number caught per pitfall trap summed over entire sample period - data for 15 raspberry fields in the Fraser Valley, BC, **A**; and number of *P. melanarius* per pitfall trap during the season, **B**.

populations. In our study, however, there was large variation between fields within a category [e.g. Fig. 1C, fields 14-15 have similar soils, but very different numbers of *P. melanarius*, so the power of the test was low (< 0.2)]. Insufficient degrees-of-freedom and non-orthogonality precluded analyzing the three factors simultaneously. The magnitude of the unexplained differences between fields suggest that further work is warranted to determine the cause. Any factors that can be manipulated culturally could be used to increase the predatory capacity of the carabid assemblage.

Table 2.

Carabids in pitfall traps in 15 commercial raspberry fields, Fraser Valley, BC. Ten traps in each field were checked and cleared weekly (26 Apr. - 30 Aug.), or bi-weekly (30 Aug. - 28 Sept.) 1994. Missing data, 46 out of 3450 trap-weeks

Species[1]	Total trapped	Observations first	Observations last	Greatest abundance[2] Period	Greatest abundance[2] Total	Greatest abundance[2] N[3]
Agonum muelleri (Herbst)+	42	26/04	28/09	09/08 - 30/08	22	440
Agonum subsericeum (LeConte)	9	26/04	13/07			
Amara spp.	561	26/04	28/09	19/04 - 10/05	330	440
Anisodactylus binotatus (Fabricius)+	1190	26/04	28/09	03/05 - 24/05	378	430
Bembidion dyschirinum LeConte	1744	26/04	28/09	19/04 - 10/05	1471	440
Bembidion iridescens (LeConte)	1	26/04	26/04			
Bembidion obscurellum (Motschulsky)*	7	26/04	08/06			
Bembidion tetracolum Say+	20	26/04	24/08	19/04 - 10/05	8	440
Bradycellus congener (LeConte)	7	26/04	26/04			
Calathus fuscipes (Goeze)+	1975	26/04	28/09	23/08 - 13/09	796	445
Carabus nemoralis O.F. Müller+	280	26/04	28/09	19/04 - 10/05	125	440
Carabus granulatus Linneaus+	727	26/04	28/09	19/04 - 10/05	326	440
Cicindela oregona LeConte	3	04/05	07/06			
Clivina fossor (Linneaus)+	215	26/04	28/09	19/04 - 10/05	117	440
Cychrus tuberculatus Harris	1	24/05	24/05			
Dyschirius globulosus (Say)	9	26/04	28/06			
Harpalus affinis (Schrank)+	290	26/04	28/09	19/04 - 10/05	131	440
Harpalus cordifer Notman	33	26/04	28/09	03/05 - 24/05	19	430
Loricera pilicornis (Fabricius)*	80	26/04	28/09	19/04 - 10/05	55	440
Notiophilus directus Casey	63	26/04	28/09	19/04 - 10/05	37	440
Omus dejeani Reiche	2	26/04	24/05			
Patrobus fossifrons (Eschscholtz)*	1	24/08	24/08			
Promecognathus crassus LeConte	1	24/05	24/05			
Pterostichus adstrictus Eschscholtz*	15	26/04	28/09	19/04 - 10/05	12	440
Pterostichus melanarius (Illiger)+	30984	26/04	28/09	09/08 - 30/08	6857	449
Pterostichus patruelis (Dejean)	3	26/04	11/05			
Synuchus impunctatus (Say)	1	20/07	20/07			
Trechus obtusus Erichson+	283	26/04	28/09	06/09 - 28/09	124	428

[1] * Holarctic; + Introduced in North America (Bousquet 1991).
[2] Greatest number of beetles per trap during 3 sequential weeks.
[3] Number of traps x weeks.

Given the differences between raspberry fields with respect to carabid beetles, it would be useful for pest managers to monitor these beneficial insects. The data obtained annually could be combined with information about the pests, and laboratory studies, to develop pest management strategies. We suggest that *P. melanarius* should be monitored. It is the most abundant species; it is easy to identify in the field; it ingests up to nine-tenths animal matter in its diet (Thiele 1977); preys on the key pests of raspberry (among other prey); and it can consume more than three times its own weight per day (Scherney 1959). Furthermore, the differences in *P. melanarius* populations between fields provide a ready-made framework for comparative studies.

Probably the most important constraint from the point of view of a pest manager is time; sampling protocols must be quick, yet provide a picture of the dynamics of pests and beneficials within a field. *Pterostichus melanarius* is a univoltine, "autumn-breeding" species (Thiele 1977), and as such, a well-timed pitfall sample should give a reasonable picture of relative population size in a field. However, the situation is complicated by the fact that some reproductive females survive the winter and reproduce again the following year. Basedow (1994) found that old females laid eggs in early June; new females began emerging at this time and laid eggs through late June and July (data were not collected in August and September). Our study suggested that the best estimate of annual abundance among fields with very different *P. melanarius* populations (Fig. 1C) could be obtained by pitfall trapping during 1-3 consecutive weeks from late June to late July. During this time, total trap catches of *P. melanarius* were most highly correlated with weekly catches (Fig. 2A). Although the result can be partially explained in terms of auto-correlation, there are periods when beetle numbers are low (Fig. 2B) but the correlation coefficient is relatively high and vice versa - early May, early June and August. The temporal variation in the correlation coefficients may be related to the phenology of the beetle, in particular the appearance of old females in May, and new females in June (Basedow 1994); the decline of the correlation coefficient in August may be related to variation in cultural practices such as cultivation after harvest. It is clear, however, that samples should be taken during the same time period when making comparisons between fields with respect to the annual abundance of *P. melanarius*. The best sampling time is probably during July when new adults have emerged and before post-harvest cultivation. Comparisons of samples between years may be misleading because year-to-year differences in factors such as weather and temperature will affect activity levels and hence the numbers caught.

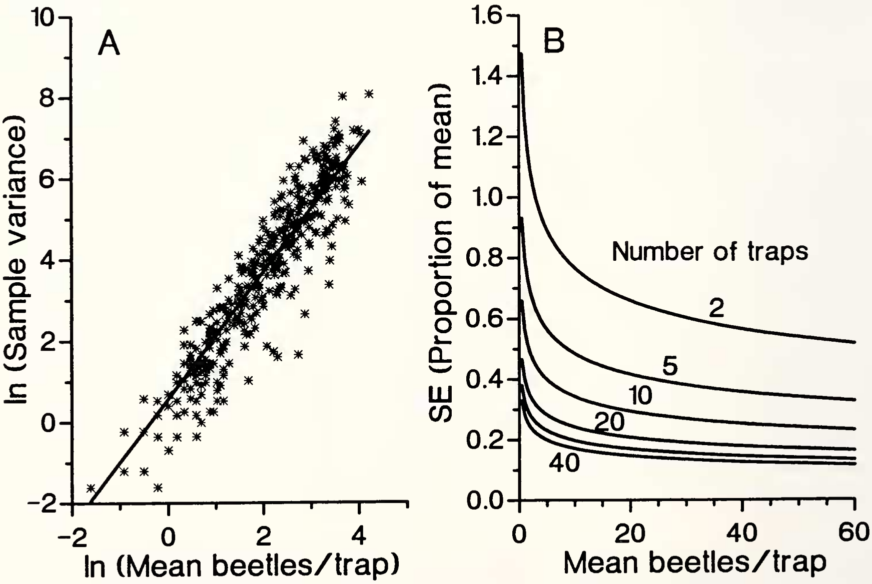

Figure. 3. Relationship between ln(sample variance) (y) and ln(mean) (x), ($y = 0.566 + 1.563 x$; respective SE's for coefficients: 0.0429 and 0.0204; remainder mean-square = 0.5212) based on weekly collections from five pitfall traps at each location in a field, **A**; and effect of number of traps and mean number of beetles per trap on standard error, expressed as a proportion of the mean **B**; data for *Pterostichus melanarius*.

Traps should be set at a standard distance from the edge of a field. Fewer *P. melanarius* were caught in traps 2 m from the edge of a field adjacent to forest or grass than at 50 m (average slope = 1.47 beetles/trap per m; SE = 0.53; n = 10). Standardizing the location of the traps will reduce some of the variation in the estimate of beetle numbers and facilitate field-to-field comparisons.

At least 10 traps are required for reasonable estimates of carabid numbers in a field. The relationship between ln(variance) and ln(mean) of five pitfall-trap catches of *P. melanarius* at 2 and 50 m in all fields during 1-week sampling intervals (Fig. 3A) was used to determine the standard error of the mean - as a proportion of the mean - for increasing numbers of traps (Fig.3B). Two traps would provide a very crude estimate of carabid populations. At 10 traps per field, 3-fold population differences could be detected (above 10 beetles per trap). Differences between fields may be as great as 30 fold, so that 10 traps should provide an adequate level of precision for management purposes.

Pitfall-trap data must be viewed cautiously when comparing species abundance across habitats, but it is well suited to studies on the impact of predators in agricultural situations (Spence and Niemela 1994). We show several ways of standardizing pitfall trapping for studies of *P. melanarius* in raspberry fields. The analyses are based on pitfall data from British Columbia, but the conclusions will probably also apply in the State of Washington, at least near the border. Comparative studies on farms near the border could provide information about the effect of different farm practices on carabid populations, in particular, chemical controls.

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